

# Structural analysis and certification

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DOI: 10.13111/2066-8201.2025.17.4.23

Received: 24 October 2025/ Accepted: 17 November 2025/ Published: December 2025

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**Abstract:** *This paper contains personal contributions discussed in a collaborative working group ICAO-IFAR DiTAC Action “Digital Transformation in Aircraft Certification” in order to highlight that the certification requirements are satisfied in a structural analysis process. Compliance with CS-25 when using FEM is demonstrated through engineering justification, correlation with test results (when available), application of appropriate safety margins, and documentation of all modelling assumptions and boundary conditions. Each analysis must provide evidence that the structural behavior meets the regulatory criteria under all applicable loading conditions. Performed structural analyses are verified for compliance with applicable EASA certification requirements, in this case, CS-25. It is described that there is no direct correspondence between CS-25 certification requirements and the FEM modelling process, since the regulation defines safety objectives, not recommending specific analysis methodologies.*

**Key Words:** *certification requirements, compliance with CS-25, EASA certification, structural analyses, FEM modelling process, IFAR, ICAO*

## 1. STRUCTURAL ANALYSIS AND CERTIFICATION IN AVIATION

Structural analysis and certification represent a cornerstone of aerospace engineering and airworthiness assurance. These processes ensure that aircraft structures are designed, analyzed, and verified to be safe, reliable, and compliant with applicable regulatory standards throughout their operational life. Through an integrated approach combining engineering analysis, physical testing, and rigorous documentation, engineers demonstrate that structural components can withstand the full range of aerodynamic, inertial, and environmental loads encountered in service.

Structural analysis encompasses the determination of loads, stress distributions, and failure modes within primary and secondary aircraft structures. Analytical and computational methods - particularly Finite Element Analysis (FEA) - are involved to assess strength, stiffness, stability, and fatigue life under critical load cases.

Certification is the formal process through which compliance with airworthiness standards is demonstrated to regulatory authorities. The applicable regulations - such as EASA CS-23/25/29 - define the minimum structural safety requirements for different classes of aircraft. Applicants must develop a Certification Plan outlining the means of compliance (analysis, test, or similarity) for each regulatory paragraph. Upon successful demonstration of compliance,

the authority issues a Type Certificate (TC) or Supplemental Type Certificate (STC), confirming that the design meets all structural and safety criteria.

Structural analysis and certification activities collectively ensure that aircraft structures maintain airworthiness, damage tolerance, and fatigue life throughout their service. These processes not only safeguard human life but also contribute to the economic efficiency and sustainability of air transport by reducing maintenance costs and preventing catastrophic failures. In essence, the integrity of the aircraft structure - and by extension, the safety of flight - rests upon the thoroughness and accuracy of the structural analysis and certification process.

## **2. STRUCTURAL ANALYSIS PROCESS AND CERTIFICATION OF AN AIRCRAFT BRACKET COMPONENT**

In modern aircraft design and certification processes, secondary structural components such as brackets play an important role in ensuring the overall integrity and safety of the airframe. Although relatively small and seemingly simple, such components are often subjected to complex loading conditions resulting from aerodynamic forces, vibration, thermal variations, and fatigue effects. If not properly analyzed and validated, these loads can lead to local failures that compromise the safety and reliability of the aircraft structure.

This theoretical study presents a comprehensive methodology as a way of work for structural analysis and certification demonstration of a bracket component used for flight control system attachment. The evaluation process includes loads application, finite element modeling (FEM), and stress and stiffness assessment in accordance with the applicable certification standards (CS-25).

The integrated approach proposed in this research highlights the importance of combining analytical, numerical, and experimental methods within the structural substantiation process. The findings contribute to a deeper understanding of the structural behavior of bracket-type components and support the development of robust engineering practices for demonstrating compliance during aircraft certification and modification programs.

This presentation includes personal research contributions developed within the framework of the collaborative working group ICAO-IFAR DiTAC Action "Digital Transformation in Aircraft Certification". The objective of this contribution is to illustrate how certification requirements are satisfied within a structural analysis process, emphasizing the integration of digital tools and standardized engineering practices in demonstrating regulatory compliance. The main objective of the study is therefore to highlight the certification criteria and methodological steps that must be fulfilled within a structural analysis and compliance demonstration framework, rather than to analyze a specific aircraft part.

### **2.1 Component Description and Structural Overview Regarding Static Strength**

An essential step in the evaluation of a bracket component is the development of an accurate finite element model (FEM) that correctly represents its geometry, boundary conditions, and load introduction paths. For the present study, a Detailed Finite Element Model (DFEM) of the bracket was created to support the static strength assessment and subsequent certification-oriented verification. The entire component was discretized using solid (CTETRA) elements, which provide adequate accuracy for complex geometries. An average element size of 2–3 mm was selected, ensuring a sufficient level of refinement for strength analysis while maintaining computational efficiency.

Load application was implemented through RBE3 elements, allowing for the realistic distribution of forces without introducing artificial stiffness. The fastener connections were

modeled using CBAR elements connected via RBE2 elements, replicating the load transfer between the bracket and its surrounding structure (as illustrated in the corresponding figure).

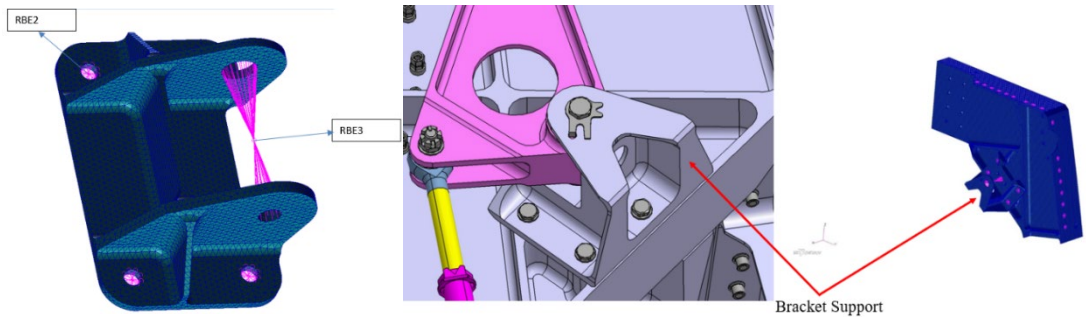


Figure 1. Bracket support

Material strength evaluations were performed based on the stress results extracted from the DFEM, analyzed using NASTRAN linear static solution SOL 101, which corresponds to a static analysis under limit load conditions. The stress distributions obtained from this analysis were subsequently used to compute margins of safety against the material’s allowable strength, ensuring compliance with the structural integrity requirements specified in the applicable certification standards

### 2.2 Correlation Between Certification Requirements and FEM-Based Structural Analysis

It is important to emphasize that there is no direct correspondence between the CS-25 certification requirements and the finite element modelling (FEM) process itself. The certification regulations define safety objectives and performance criteria, but they do not prescribe specific analytical methodologies or modelling practices. Consequently, the use of FEM in the certification context serves as an engineering tool to demonstrate compliance, rather than a mandated procedure. The accuracy and reliability of FEM results depend on several factors, including the convergence of the numerical solution (used to determine appropriate mesh density), the application of engineering judgment (in selecting element types, defining boundary conditions, and identifying load introduction points), and project-specific constraints such as available test data or simulation resources.

In general, each aerospace company develops its own Detailed FEM Modelling Guidelines, based on prior experience, validated test results, and correlation between simulation and experimental data. These internal standards govern the level of mesh refinement, element quality, and modelling assumptions adopted during the analysis phase.

Validation of the FEM model is typically performed using a structured checklist to ensure accuracy, consistency, and compliance with design and analysis standards. Common verification criteria include aspect ratio, edge angle, face skew angle, and collapse ratio, which collectively assess the geometric quality and numerical stability of the mesh [2].

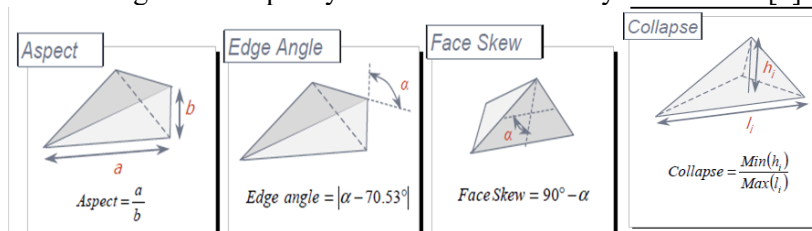


Figure 2. Finite Element Mesh Quality Parameters

Compliance with CS-25 structural requirements when using FEM is therefore demonstrated through a combination of engineering justification, correlation with test results (when available), and the application of appropriate safety margins. All modelling assumptions, boundary conditions, and load applications must be clearly documented, ensuring full traceability and transparency in the certification process. Ultimately, each analysis must provide credible evidence that the predicted structural behavior satisfies the applicable regulatory safety criteria under all relevant loading conditions.

### 2.3 Civil Certification Requirements

The bracket under investigation has been designed in accordance with the civil airworthiness requirements defined by EASA CS-25, Amendment 28 [1].

The performed structural analyses have been reviewed and verified to ensure compliance with the applicable EASA certification requirements specified in CS-25. The verification process aligns the analytical results with the relevant regulatory paragraphs, ensuring that all design and substantiation activities meet the prescribed safety and performance criteria.

A summary of the CS-25 requirements applicable to this component and their corresponding means of compliance is presented in the table below:

Table 1. Summary of Applicable CS-25 Requirements

CS 25	25.301	Loads
	25.303	Factor of Safety
	25.305a	Strength and deformation – LL
	25.305b	Strength and deformation – UL
	25.307a	Proof of Structure – critical loading conditions
	25.321	Flight Loads
	25.395	Control System
	25.397	Limit pilot forces and torques
	25.399	Dual Control System
	25.471	Ground Loads
	25.603	Materials
	25.613	Material Strength Properties and Design Values
	25.625	Fitting Factors

#### CS-25.301 Loads [1] (pag. 184)

### CS 25.301 Loads

(See AMC 25.301)

- (a) Strength requirements are specified in terms of limit loads (the maximum loads to be expected in service) and ultimate loads (limit loads multiplied by prescribed factors of safety). Unless otherwise provided, prescribed loads are limit loads.

The structural stress analysis process begins with the stress sizing phase, which entails the application of both limit and ultimate loads in accordance with CS-25 regulatory requirements. This approach ensures that the structure is adequately dimensioned to withstand critical loading conditions defined by the certification specifications.

So:

Stress Sizing results using maximum stress tensor loads:

Limit loads case 1 (taken as an example):  $F_x = -256 \text{ N}$        $M_x = 0 \text{ N}\cdot\text{mm}$   
 $F_y = 1835 \text{ N}$        $M_y = -10335 \text{ N}\cdot\text{mm}$

$F_z = 2359 \text{ N}$      $M_z = 17008 \text{ N}\cdot\text{mm}$

$UL = LL \cdot SF$  [4.]

SF=safety factor applied and considered

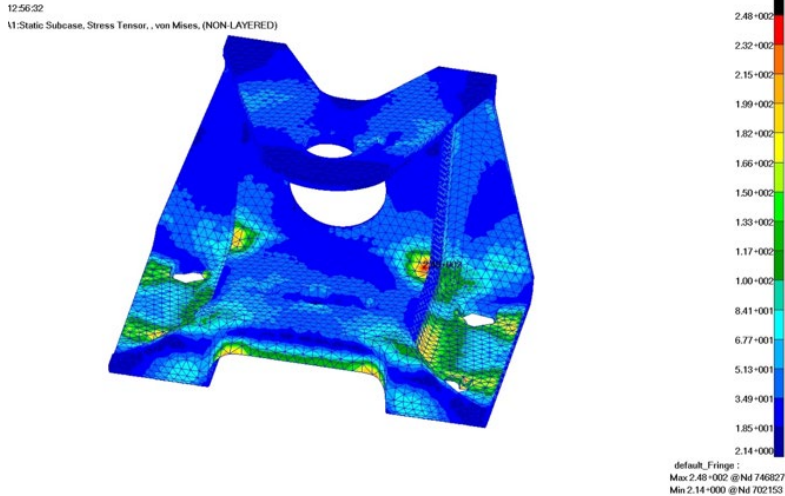


Figure 3. Results using maximum stress tensor loads from Control System Envelope

Following the application of loads and considering the boundary conditions, this is the resulting stress distribution in the analyzed bracket, as obtained from the structural analysis. Material strength calculations are carried out based on stresses extracted from the DFEM analyzed with NASTRAN linear solution SOL101.

The stresses from DFEM are extracted according maximum value obtained from the plots (see above figure) and used for the margin of safety calculation.

**CS-25.303 Factor of Safety [1] (pag. 189)**

**CS 25.303 Factor of safety**

Unless otherwise specified, a factor of safety of 1.5 must be applied to the prescribed limit load which are considered external loads on the structure. When loading condition is prescribed in terms of ultimate loads, a factor of safety need not be applied unless otherwise specified.

According to CS 25.303, the safety factor linking the design limit load (LL) and the ultimate loads (UL) is 1.50.

$$\frac{\text{Ultimate Load}}{\text{Limit Load}} = 1.50$$

Example Calculation for min MS:

Applied Stress: 248 MPa  
 Allowable: 1070 MPa  
 Temp KDF: 0.93

Temperature [°C]	Temperature [°F]	Material	F <sub>tu</sub> Temp KDF	F <sub>ty</sub> Temp KDF	F <sub>bru</sub> Temp KDF	F <sub>bry</sub> Temp KDF
85	185	15-5PH H1025	0.93	0.93	0.93(*)	0.93(*)

$$MS = \frac{F_{tu} \cdot KDF_{Temp}}{\sigma_{vonMises}} - 1 = \frac{1070 \cdot 0.93}{248 \cdot 1.5} - 1 = 1.67$$

**CS-25.305a,b Strength and deformation [1] (pag. 189)****CS 25.305 Strength and deformation**

- (a) The structure must be able to support limit loads without detrimental permanent deformation. At any load up to limit loads, the deformation may not interfere with safe operation.
- (b) The structure must be able to support ultimate loads without failure for at least 3 seconds. However, when proof of strength is shown by dynamic tests simulating actual load conditions, the 3-second limit does not apply. Static tests conducted to ultimate load must include the ultimate deflections and ultimate deformation induced by the loading. When analytical methods are used to show compliance with the ultimate load strength requirements, it must be shown that –
- (1) The effects of deformation are not significant;
  - (2) The deformations involved are fully accounted for in the analysis; or
  - (3) The methods and assumptions used are sufficient to cover the effects of these deformations.

From the example, the stress is below the material yield strength (no detrimental permanent deformation) at LL with SF=1 and below the material ultimate strength (no failure of the structure) at UL with SF=1.5 [4, 8].

Example Calculation for min MS:

Applied Stress:	248 MPa
Allowable:	1070 MPa
Temp KDF:	0.93

$$MS = \frac{F_{tu} \cdot KDF_{Temp}}{\sigma_{vonMises}} - 1 = \frac{1070 \cdot 0.93}{248 \cdot 1.5} - 1 = 1.67$$

Example Calculation for min MS:

Applied Stress:	248 MPa
Allowable:	985 MPa
Temp KDF:	0.93

$$MS = \frac{F_{ty} \cdot KDF_{Temp}}{\sigma_{vonMises}} - 1 = \frac{985 \cdot 0.93}{248 \cdot 1} - 1 = 2.69$$

**CS-25.307a Proof of Structure- critical loading conditions [1] (pag. 189-190)****CS 25.307 Proof of structure**

(See [AMC 25.307](#))

- (a) Compliance with the strength and deformation requirements of this Subpart must be shown for each critical loading condition. Structural analysis may be used only if the structure conforms to that for which experience has shown this method to be reliable. In other cases, substantiating tests must be made to load levels that are sufficient to verify structural behaviour up to loads specified in [CS 25.305](#).

Compliance with strength and deformation requirements were demonstrated for all critical loading conditions (like was stated in the previous pages). This method of evaluating the brackets structure has proven reliability through prior experience.

**CS-25.321 Flight Loads [1] (pag. 195)****CS 25.321 General**

- (a) Flight load factors represent the ratio of the aerodynamic force component (acting normal to the assumed longitudinal axis of the aeroplane) to the weight of the aeroplane. A positive load factor is one in which the aerodynamic force acts upward with respect to the aeroplane.
- (b) Considering compressibility effects at each speed, compliance with the flight load requirements of this Subpart must be shown –
- (1) At each critical altitude within the range of altitudes selected by the applicant;
  - (2) At each weight from the design minimum weight to the design maximum weight appropriate to each particular flight load condition; and
  - (3) For each required altitude and weight, for any practicable distribution of disposable load within the operating limitations recorded in the Aeroplane Flight Manual.

For a structure that meets the above requirement, flight loads, weight ranges and load distributions compliance has been included in all that critical loading cases which were used in analysis. Compressibility effects were accounted for at each relevant speed, ensuring the structure satisfies the applicable flight load conditions.

### CS-25.395c Control System [1] (pag. 242-243)

#### CS 25.395 Control system

- (c) The loads must not be less than those resulting from application of the minimum forces prescribed in [CS 25.397\(c\)](#).

The applied loads must meet or exceed the minimum forces specified in CS 25.397. This ensures that control surface and system strength requirements are satisfied under critical loading conditions which are specified in CS25.397c [1].

### CS-25.397c Control System Loads [1] (pag. 243)

#### CS 25.397 Control system loads

- (a) *General.* The maximum and minimum pilot forces, specified in sub-paragraph (c) of this paragraph, are assumed to act at the appropriate control grips or pads (in a manner simulating flight conditions) and to be reacted at the attachment of the control system to the control surface horn.
- (b) *Pilot effort effects.* In the control surface flight loading condition, the air loads on movable surfaces and the corresponding deflections need not exceed those that would result in flight from the application of any pilot force within the ranges specified in sub-paragraph (c) of this paragraph. Two-thirds of the maximum values specified for the aileron and elevator may be used if control surface hinge moments are based on reliable data. In applying this criterion, the effects of servo mechanisms, tabs, and automatic pilot systems, must be considered.
- (c) *Limit pilot forces and torques.* The limit pilot forces and torques are as follows:

Control	Maximum forces or torques	Minimum forces or torques
Aileron:		
Stick	445 N (100 lbf)	178 N (40 lbf)
Wheel*	356 DNm (80 D in.lb)**	178 DNm (40 D in.lbf)
Elevator:		
Stick	1112 N (250 lbf)	445 N (100 lbf)
Wheel (symmetrical)	1335N(300 lbf)	445 N(100 lbf)
Wheel (unsymmetrical)†		445 N (100 lbf)
Rudder	1335 N (300 lbf)	578 N 130 lbf

\*The critical parts of the aileron control system must be designed for a single tangential force with a limit value equal to 1.25 times the couple force determined from these criteria.

For the stiffness consideration, the method includes to calculate a maximum displacement, as example for the control at stick where the maximum force equals 445N.

*Limit pilot forces and torques.* The limit pilot forces and torques are as follows:

Control	Maximum forces or torques	Minimum forces or torques
Aileron:		
Stick	445 N (100 lbf)	178 N (40 lbf)
Wheel*	356 DNm (80 D in.lb)**	178 DNm (40 D in.lbf)

A stiffness evaluation was made for the bracket according with the value from the table above:

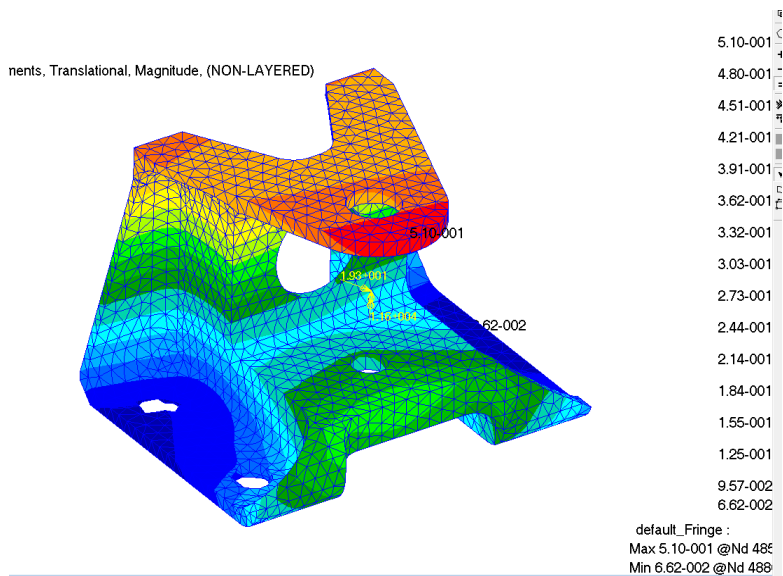


Figure 4. Displacement Plot of the bracket from PATRAN

### CS-25.399 Dual Control System [1] (pag. 244)

#### CS 25.399 Dual control system

- (a) Each dual control system must be designed for the pilots operating in opposition, using individual pilot forces not less than –
- (1) 0.75 times those obtained under [CS 25.395](#); or
  - (2) The minimum forces specified in [CS 25.397\(c\)](#).
- (b) The control system must be designed for pilot forces applied in the same direction, using individual pilot forces not less than 0.75 times those obtained under [CS 25.395](#).

For each part calculated which makes the subject of flight control system brackets were considered both, loads and their opposites for stress and stiffness evaluation (symmetrical loading).

Limit loads **case 2** (opposite to load case 1 presented on page 4):  $F_x=256\text{ N}$      $M_x=0\text{ N}\cdot\text{mm}$   
 $F_y=-1835\text{ N}$      $M_y=10335\text{ N}\cdot\text{mm}$   
 $F_z=-2359\text{ N}$      $M_z=-17008\text{ N}\cdot\text{mm}$

### CS-25.471 Ground Loads [1] (pag. 249)

#### GROUND LOADS

##### CS 25.471 General

- (a) *Loads and equilibrium.* For limit ground loads –
- (1) Limit ground loads obtained under this Subpart are considered to be external forces applied to the aeroplane structure; and
  - (2) In each specified ground load condition, the external loads must be placed in equilibrium with the linear and angular inertia loads in a rational or conservative manner.

The Flight/Ground/Global Landing load case group is considered for the static strength substantiation of the Primary Structure Area affected by Flight Controls loading influence [1].

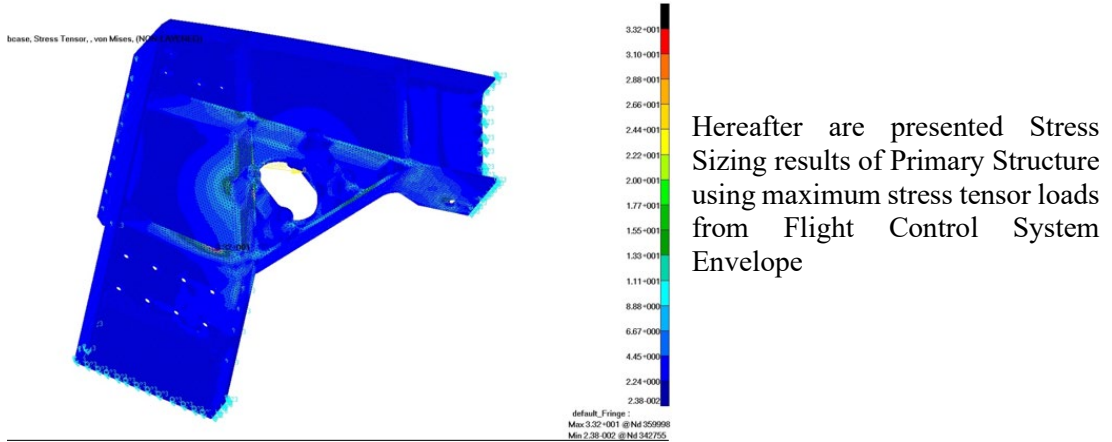


Figure 5. Von Mises Plot from PATRAN

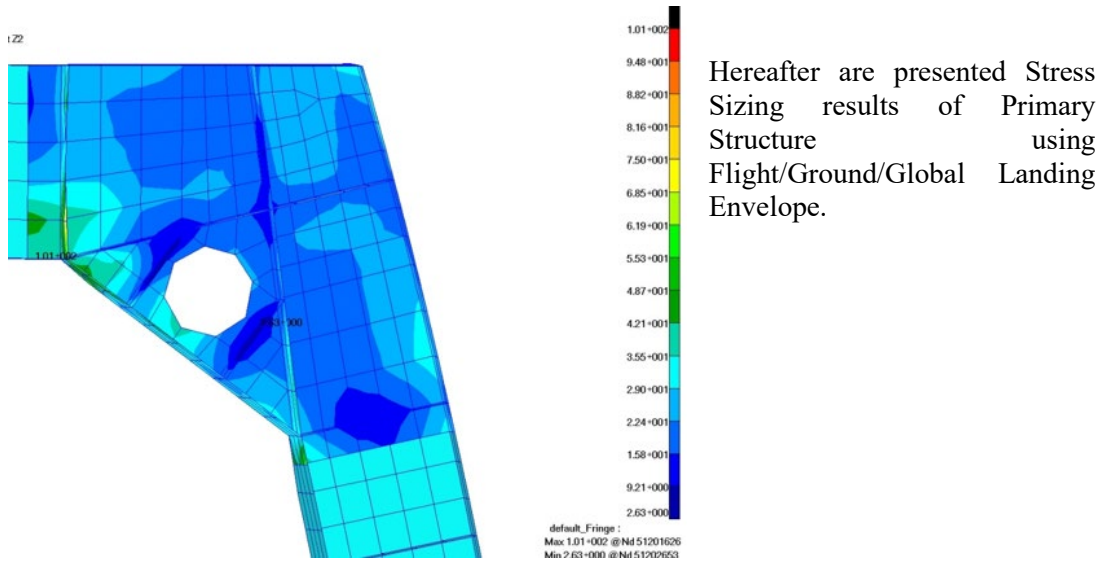


Figure 6. Von Mises Plot from PATRAN

Superposition of stresses of the bracket with the primary structure was performed and a margin of safety was calculated [4, 8].

Example Calculation for min MS:

Applied Stress: 33.2+101.2 MPa

Allowable: 505 MPa

Temp KDF: 0.89

For superposition bracket/primary structure the applied stress is 101 MPa + 33.2 MPa

$$MS = \frac{F_{tu} \cdot KDF_{Temp}}{\sigma_{vonMises}} - 1 = \frac{505 \cdot 0.89}{(101.2 + 33.2) \cdot 1.5} - 1 = 1.22$$

**CS-25.603 Materials [1] (pag. 330)****CS 25.603 Materials**

(See [AMC 25.603](#); for composite materials, see [AMC 20-29](#); for use of glass in passenger cabins, see [AMC No 2 to CS 25.603\(a\)](#))

The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must:

- (a) be established on the basis of experience or tests; (see [AMC No\\*1 to CS 25.603\(a\)](#));
- (b) conform to approved specifications that ensure their having the strength and other properties assumed in the design data (see [AMC 25.603\(b\)](#)); and
- (c) take into account the effects of environmental conditions, e.g. temperature and humidity, expected in service.

Temperature [°C]	Temperature [F]	Material	F <sub>tu</sub> Temp KDF	F <sub>ty</sub> Temp KDF	F <sub>bru</sub> Temp KDF	F <sub>bry</sub> Temp KDF
85	185	15-5PH H1025	0.93	0.93	0.93(*)	0.93(*)

Metallic Materials Properties Development and Standardization- MMPDS [3]

In order to comply with these requirements, for material strength calculation the thermal effect was sustained by the Temperature KDFs based on the Temperature mapping. In the MS calculation is integrated also the temperature correction factor  $KDF_{Temp}$ .

**CS-25.613 Material Strength Properties and Design Values [1] (pag. 339-340)****CS 25.613 Material strength properties and Material Design Values**

(See [AMC 25.613](#))

- (a) Material strength properties must be based on enough tests of material meeting approved specifications to establish design values on a statistical basis.
- (b) Material design values must be chosen to minimise the probability of structural failures due to material variability. Except as provided in sub-paragraphs (e) and (f) of this paragraph, compliance must be shown by selecting material design values which assure material strength with the following probability:
  - (1) Where applied loads are eventually distributed through a single member within an assembly, the failure of which would result in loss of structural integrity of the component, 99% probability with 95% confidence.
  - (2) For redundant structure, in which the failure of individual elements would result in applied loads being safely distributed to other load carrying members, 90% probability with 95% confidence.

**AMC 25.613 Material strength properties and material design values**

1. *Purpose.* This AMC sets forth an acceptable means, but not the only means, of demonstrating compliance with the provisions of CS-25 related to material strength properties and material design values.
- 4.5. *Other Material Design Values.* Previously used material design values, with consideration of the source, service experience and application, may be approved by the Agency on a case by case basis (e.g. "S" values of "The Metallic Materials Properties Development and Standardization (MMPDS) handbook" or ESDU 00932).

Table 2. MIL-HDBK 5F [7] (pag. 2-158)

15-SPH (Ref.: MIL-HDBK 5F)

Temper			H900	H925	H1025	H1075	H1100	H1150
Thickness [mm]			± 300	± 300	± 300	± 300	± 300	± 300
Statistical Base			S	S	S	S	S	S
$R_m$	MPa	L	1310	1170	1070	1000	965	930
		T	1310	1170	1070	1000	965	930
$R_{p0.2}$	MPa	L	1170	1070	1000	860	795	725
		T	1170	1070	1000	860	795	725
$R_{t0.2}$	MPa	L			985			685
		T			985			685
$R_{su}$	MPa			670			585	
$R_{bru}$	MPa	$e/d = 1.5$			1815			1585
		$e/d = 2.0$			2290			2020
$R_{bry}$	MPa	$e/d = 1.5$			1455			1145
		$e/d = 2.0$			1725			1385
A	%	L	10	10	12	13	14	16
		T	6	7	8	9	10	11

Compliance for this requirement was satisfied by material selection presented in table above.

### CS-25.625 Fitting Factors [1] (pag. 325)

#### CS 25.625 Fitting factors

For each fitting (a part or terminal used to join one structural member to another), the following apply:

- (a) For each fitting whose strength is not proven by limit and ultimate load tests in which actual stress conditions are simulated in the fitting and surrounding structures, a fitting factor of at least 1.15 must be applied to each part of –
- (1) The fitting;
  - (2) The means of attachment; and
  - (3) The bearing on the joined members.

Bearing Allowable	$F_{bru(e/d=1.5)} = 735 \text{ MPa}$
Single Shear Allowable	$F_{s,alw} = 8835 \text{ N}$
Tension Allowable	$F_{t,alw} = 10270 \text{ N}$
Ultimate shear allowable	$F_{su} = 290 \text{ MPa}$
Fitting Factor	1.15
Temp KDF	0.89
Safety Factor	1.5
Maximum Applied Loads at interface:	

$$F_{s,app,NodeID579191} = \sqrt{(851N)^2 + (299N)^2} = 902N$$

$$F_{t,NodeID579191} = 1547.3N$$

$$F_{b,alw} = t * d * R_{bru} = 7 * 5.0 * 735 = 25725 \text{ N}$$

$$MS_{Bearing} = \frac{F_{b,alw} \cdot KDF_{Temp}}{F_{s,app} \cdot FF \cdot SF} - 1 = \frac{25725 \cdot 0.89}{902 \cdot 1.15 \cdot 1.5} - 1 = 13.71$$

$$MS_{Shear} = \frac{F_{s,alw} \cdot KDF_{Temp}}{F_{s,app} \cdot SF \cdot FF} - 1 = \frac{8835 \cdot 0.89}{902 \cdot 1.5 \cdot 1.15} - 1 = 4.05$$

$$MS_{Tension} = \frac{F_{t,alw} \cdot K \cdot KDF_{Temp}}{F_{t,app} \cdot FF \cdot SF} - 1 = \frac{10270 \cdot 0.89}{1547.3 \cdot 1.5 \cdot 1.15} - 1 = 2.42$$

### 3. CONCLUSIONS

The present study demonstrates a structured approach for performing structural analysis and certification verification of a bracket component. The analysis methodology, based on finite element modeling (FEM), has proven effective for assessing the static strength and compliance with the applicable EASA CS-25, Amendment 28 certification requirements [1].

Although the CS-25 regulations establish only safety objectives and do not prescribe specific analytical methods, the application of FEM—when combined with engineering judgment, validation criteria, and correlation with test data—provides a reliable means to demonstrate compliance with airworthiness standards. The Detailed Finite Element Model (DFEM), supported by appropriate mesh quality control and convergence checks, allows for accurate prediction of stress distributions and margin-of-safety evaluations under limit and ultimate load conditions.

The study also emphasizes that FEM validation is a critical part of the certification process. The accuracy and credibility of the analysis depend on rigorous verification of model parameters such as element aspect ratio, edge angle, face skew, and collapse ratio, as well as on adherence to internally defined modelling guidelines based on previous experience and correlation with physical tests.

By adopting this systematic approach, compliance with CS-25 structural integrity requirements can be demonstrated through transparent engineering justification, consistent documentation, and clear traceability of assumptions and boundary conditions. The methodology described herein can be generalized and applied to other aircraft components, supporting the digital transformation of certification processes in line with ongoing ICAO–IFAR DiTAC initiatives.

Future research will aim to extend the current methodology toward dynamic and fatigue analyses, enabling a more comprehensive assessment of the bracket’s behavior under cyclic and transient loading conditions. These studies will enhance understanding of damage tolerance and durability in other structural components. In parallel, efforts will focus on developing digital certification frameworks that seamlessly integrate numerical simulation, experimental validation, and compliance verification within a unified digital ecosystem [9].

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